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M.R.P. 1035
22nd January, 1957

AIR MINISTRY

METEOROLOGICAL RESEARCH COMMITTEE

(Paper circulated for the information of members of the Meteorological Research Committee and the Sub-Committees.)

## Extension to the Standard Atmosphere

The paper consists of three parts:-

I - Document from the Co-Chairmen of the Committee on Extension to the Standard Atmosphere, Geophysics Research Directorate, Boston, Massachusetts (as circulated by the Royal Society to the Gassiot Committee)

II - Comments by Dr. A.H.R. Goldie (formerly of the Meteorological Office) to the Royal Society, 8th December, 1956.

III - Comments by Mr. B.C.V. Oddie (Meteorological Office), 7th January, 1957.

## I

Committee on Extension to the Standard Atmosphere++
U.S. Weather Bureau and Geophysics Research Directorate (AFCRC), Co-sponsors

### ANNOUNCEMENT

A new extension to the 20 kilometer ICAO Standard Atmosphere (the accepted U.S. standard) is being adopted by about 23 United States scientific and engineering organizations; this extension provides tables of atmospheric parameters up to 300 kilometers. Because of their great need for such tables and because many have active high altitude research programs, these organizations met in November, 1953 to seek agreement upon a single representation of the atmosphere compatible with the best available data. The United States Weather Bureau of the Department of Commerce and the Geophysics Research Directorate, Air Force Cambridge Research Centre of the Air Research Development Command, co-sponsored this movement which included the following participants:

Air Research and Development Command
+Air Technical Intelligence Centre
Air Weather Service
Applied Physics Laboratory
Ballistics Research Laboratory
Boston University (member transferred to Sylvania)
Bureau of Aeronautics, USN
Civil Aeronautics Authority
CONVAIR, San Diego
CONVAIR, Fort Worth
Geophysics Research Directorate (AFCRC)
Harvard College Observatory
+International Civil Aviation Organization
Jet Propulsion Laboratory
National Bureau of Standards
Naval Proving Grounds
Naval Research Laboratory

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++ Address: Geophysics Research Directorate, 415 Summer St., Boston 10, Mass.
+ Observer

Office of the Chief Signal Officer
The Rand Corporation
Redstone Arsenal (ABMA)
Signal Corps Engineering Laboratory
United States Weather Bureau
White Sands Proving Grounds
Wright Air Development Centre

A working group was appointed to study the problem. This group met several times since 1953 and recommended the basic values and parameters shown in Table 1. These values have now been approved by nearly all the participants listed above. A curve of $T_M$ vs. H is shown in Figure 1.

Extensive tables expanding the basic framework of Table 1 are currently under preparation at the Geophysics Research Directorate and will follow closely the format of the ICAO Standard Atmosphere which appears as ICAO Document 7488, NACA TN 3182, and NACA Report 1235; moreover additional information, important at higher altitudes, such as gravity ratio and molecular weight will be included. Supplemental information to describe the variability of the atmosphere and other parameters will be issued later as appendices. Preliminary copies of these tables, in a form analogous to the NACA TN 3182 should be available in limited quantities during 1957. It is planned to have the final edition printed by the Government Printing Office and made available to the public through the Superintendent of Documents.

By virtue of the wide participation in this effort, these 23 organizations established a U.S. Standard and are planning action through the Air Coordinating Committee and ICAO to obtain international acceptance for the lowest portion (20 to 32 kilometers) of the tables. In this regard, it should be noted that the 75 to 300 kilometer interval of the extension is termed 'Speculative Atmosphere', since it is felt that new experimental data obtained over the next five or ten years may lead to a better representation. The interval, 32 kilometers to 75 kilometers, has been termed 'Tentative Atmosphere', since more data may also lead to modification and also because any drastic change in the 'Speculative Atmosphere' may require some change in the adjacent lower levels. The 20 to 32 kilometer level is termed 'Standard', since it is a good compromise between the voluminous radiosonde data of the meteorological services and tables already firmly entrenched in the development of engineering equipment. No changes are forseen for this level.

Geophysics Research Directorate scientists, R.A. Minzner, and W.S. Ripley, are now preparing the completed report.

HARRY WEXLER — USWB
NORMAN SISSENWINE — GRD, AFCRC
Co-Chairmen
Committee on Extension to the Standard Atmosphere

NOTE: Groups within the U.S. Air Force's Air Research and Development Command or under contract to ARDC who have had occasion to use 'The ARDC MODEL ATMOSPHERE, 1956', will be pleased to note that ARDC tables are based upon and are consistent with the new U.S. extension to the ICAO Standard Atmosphere.

G.H5320/MKR/2/57/100

Table 1

United States Extension to the Standard Atmosphere

| H (m') | Z (m) | L (°/m') | $T_M$ (°K) | T (°K) | M (gr/mole) | P (mb) |
|---|---|---|---|---|---|---|
| 0.00 | 0.00 | -0.0065 | 288.16 | 288.16 | 28.966 | $1.01325 \times 10^{3}$ |
| 11,000.0 | 11,019 | 0.0000 | 216.66 | 216.66 | 28.966 | $2.2632 \times 10^{2}$ |
| +20,000.0 | 20,063 | 0.0000 | 216.66 | 216.66 | 28.966 | $5.4748 \times 10^{1}$ |
| 25,000.0 | 25,099 | 0.0030 | 216.66 | 216.66 | 28.966 | $2.4886 \times 10^{1}$ |
| +32,000.0 | 32,162 | 0.0030 | 237.66 | 237.66 | 28.966 | $8.6776 \times 10^{0}$ |
| 47,000.0 | 47,350 | 0.0000 | 282.66 | 282.66 | 28.966 | $1.2044 \times 10^{0}$ |
| 53,000.0 | 53,446 | -0.0039 | 282.66 | 282.66 | 28.966 | $5.8320 \times 10^{-1}$ |
| 75,000.0 | 75,895 | 0.0000 | 196.86 | 196.86 | 28.966 | $2.4521 \times 10^{-2}$ |
| 90,000.0 | 91,294 | 0.0035 | 196.86 | 196.86 | 28.966 | $1.8154 \times 10^{-3}$ |
| 126,000.0 | 128,548 | 0.0100 | 322.86 | 278.88++ | 25.02++ | $1.4510 \times 10^{-5}$ |
| 175,000.0 | 179,954 | 0.0058 | 812.86 | 686.13++ | 24.45++ | $6.1895 \times 10^{-7}$ |
| 300,000.0 | 314,859 | | 1537.86 | 10024.67++ | 19.30++ | $1.4473 \times 10^{-8}$ |

+Top of current ICAO Standard and top of recommended extension for standardization - no discontinuity in temperature-height curve.

++Approximate values subject to minor revision depending upon recomputation of M above 90 km.

Z - Altitude in geometric meters
H - Altitude in geopotential meters
L - Temperature lapse rate in Kelvin degrees per geopotential meter
$T_M$ - Molecular-scale temperature in degrees Kelvin
T - Real kinetic temperature in degrees Kelvin
M - Molecular weight in grams per mole
P - Pressure in millibars

II

Comments by Dr. A.H.R. Goldie

You have sent me a copy of an extension which a United States Committee propose to make to the 'Standard Atmosphere'. I have not got by me all the data I should like to consult in commenting upon this matter and I am doing so mainly on data not going beyond 45 km which had come to my notice prior to my retirement in 1953. The Meteorological Office could perhaps comment in greater detail on the proposed extension.

The original 'Standard Atmosphere' of the I.C.A.N., which is used as the basis of graduation of altimeters and for aircraft design purposes generally, corresponds roughly to the annual average or to the average between summer and winter conditions in temperate latitudes in the northern hemisphere. The I.C.A.N. Atmosphere extends only to 15 km. For design purposes for which this average condition is not enough, there are recognized values for 'Tropical Summer Standard', 'Temperate Summer Standard' and 'Sub-Arctic Winter'.

The newly proposed U.S.A. extension adopts the original standard average I.C.A.N. atmosphere up to 15 km and extrapolates this to 25 km, then it appears to abandon the idea of the annual average condition and at 32 km and at 47 km it passes over to something corresponding closely to midsummer conditions in temperate or high latitudes.

It would be quite reasonable to accept the values proposed by U.S.A. up to 25 km; because, up to that height, there is no vast divergence between summer and winter averages in temperate latitudes. The difference amounts to roughly 15°C at 25 km and the U.S.A. extrapolation lies between and rather nearer to the winter than to the summer mean. At 32 km, however, there is good reason to believe that the summer means temperature is of the order of 25°C greater than the winter mean and at 45 km it is probably about 70°C warmer. I do not think that there is any getting away from this conclusion, because it also makes the observed seasonal wind directions fit with the computed pressure pattern.

Beyond about 45 km, I do not know whether there are yet adequate and sound observational data to estimate the difference between summer and winter temperatures; but I should not be surprised if it ultimately turns out to be even greater at greater hights. As to the 'speculative' part of the U.S.A. curve, showing both the very cold part between 75 and 90 km and the very warm part beyond 126 km with temperatures rising to over 1,500°K at 300 km, the ionospheric people will doubtless have something to say on this point and, in particular, on whether these are thought to occur together.

In brief, the United States curve seems to me to be a kind of hybrid. I think it would be better either to aim at two curves, one relating to summer conditions, the other to winter conditions in temperate latitudes, and possibly extending to 45 km; or, alternatively, to adopt only an average curve, in this case not going beyond 25 km or 30 km.

## III

## Comments by Mr. B.C.V. Oddie

It is a little difficult to see the logical principle on which the extended standard atmosphere is based. Up to 20 km it is identical with the I.C.A.O. standard atmosphere, and this approximates to the mean conditions over over Northwest Europe. Therefore, one would expect the extension also to represent mean conditions over Northwest Europe - that is, for a latitude of about 50°. In fact, however, the extension approximates very closely to the mean summer conditions in any latitude from 0° to 50°. This may be verified by reference to Table 2, attached, which shows, for latitudes 30°N, 50°N and 70°N the relationship between height and

(a) Temperature according to the extended standard atmosphere

(b) Estimated mean summer temperatures

(c) Estimated mean winter temperatures.

Between 25 and 60 km the winter temperatures are substantially lower than the summer temperatures and, therefore, than the standard temperatures. The difference is quite small at 30°N, but increases steadily towards the pole. For any given latitude it is always greatest at a height of about 50 km, the maximum values being roughly 13°C at 30°N, 37°C at 50°N and 47°C at 70°N. These values of the difference between summer and winter temperatures are less than those mentioned by Dr. Goldie, but are still considerable in comparison with the total range of little more than 100°C within which the air temperature in the lowest 100 km always lies.

Thus, as Dr. Goldie says, the proposed standard atmosphere is a "sort of hybrid". In the lowest 25 km it corresponds approximately to annual mean conditions in Southern England, whereas between 25 and 60 km it corresponds to summer conditions in latitudes 30 to 50°. At all latitudes north of about 45° this section (25 to 60 km) is a poor representation of winter conditions. From 60 km to 80 km summer temperatures in latitudes 30° and 50° differ little from winter temperatures or from the proposed standard which is, therefore, satisfactory at these heights.

No comments are offered on the section above 80 km. The suggested conditions are certainly not unreasonable, and the authors of the proposal themselves describe this section as "speculative": with which one can only agree.

Table 2

Comparison of mean summer temperatures and mean winter temperatures with the proposed "standard atmosphere"

Latitude 30°N

| Height (Km) | Standard Temperature °A | Mean Summer Temperature °A | Mean Winter Temperature °A |
|---|---|---|---|
| 25 | 217 | 219 | 212 |
| 30 | 232 | 232 | 220 |
| 35 | 247 | 246 | 233 |
| 40 | 262 | 263 | 252 |
| 45 | 277 | 277 | 264 |
| 50 | 283 | 279 | 272 |
| 55 | 275 | 268 | 260 |
| 60 | 255 | 254 | 254 |
| 70 | 216 | 221 | 220 |
| 80 | 197 | 200 | 200 |

Latitude 50°N

| Height (Km) | Standard Temperature °A | Mean Summer Temperature °A | Mean Winter Temperature °A |
|---|---|---|---|
| 25 | 217 | 227 | 214 |
| 3 30 | 232 | 235 | 213 |
| 35 | 247 | 248 | 222 |
| 40 | 262 | 264 | 238 |
| 45 | 277 | 279 | 248 |
| 50 | 283 | 293 | 256 |
| 55 | 275 | 281 | 261 |
| 60 | 255 | 258 | 260 |
| 70 | 216 | 216 | 224 |
| 80 | 197 | 198 | 210 |

Latitude 70°N

| Height (Km) | Standard Temperature °A | Mean Summer Temperature °A | Mean Winter Temperature °A |
|---|---|---|---|
| 25 | 217 | 234 | 204 |
| 30 | 232 | 238 | 203 |
| 35 | 247 | 248 | 214 |
| 40 | 262 | 261 | 237 |
| 45 | 277 | 271 | 234 |
| 50 | 283 | 289 | 242 |
| 55 | 275 | 288 | 253 |
| 60 | 255 | - | - |
| 70 | 216 | - | - |
| 80 | 197 | - | - |

The mean summer and winter temperatures are taken from a table prepared by Mr. R. J. Murgatroyd in connexion with an article on winds and temperatures in the upper atmosphere (20 to 100 km) which he has recently completed and which the Royal Meteorological Society proposes to publish as one of their series of "Reviews of Modern Meteorology".

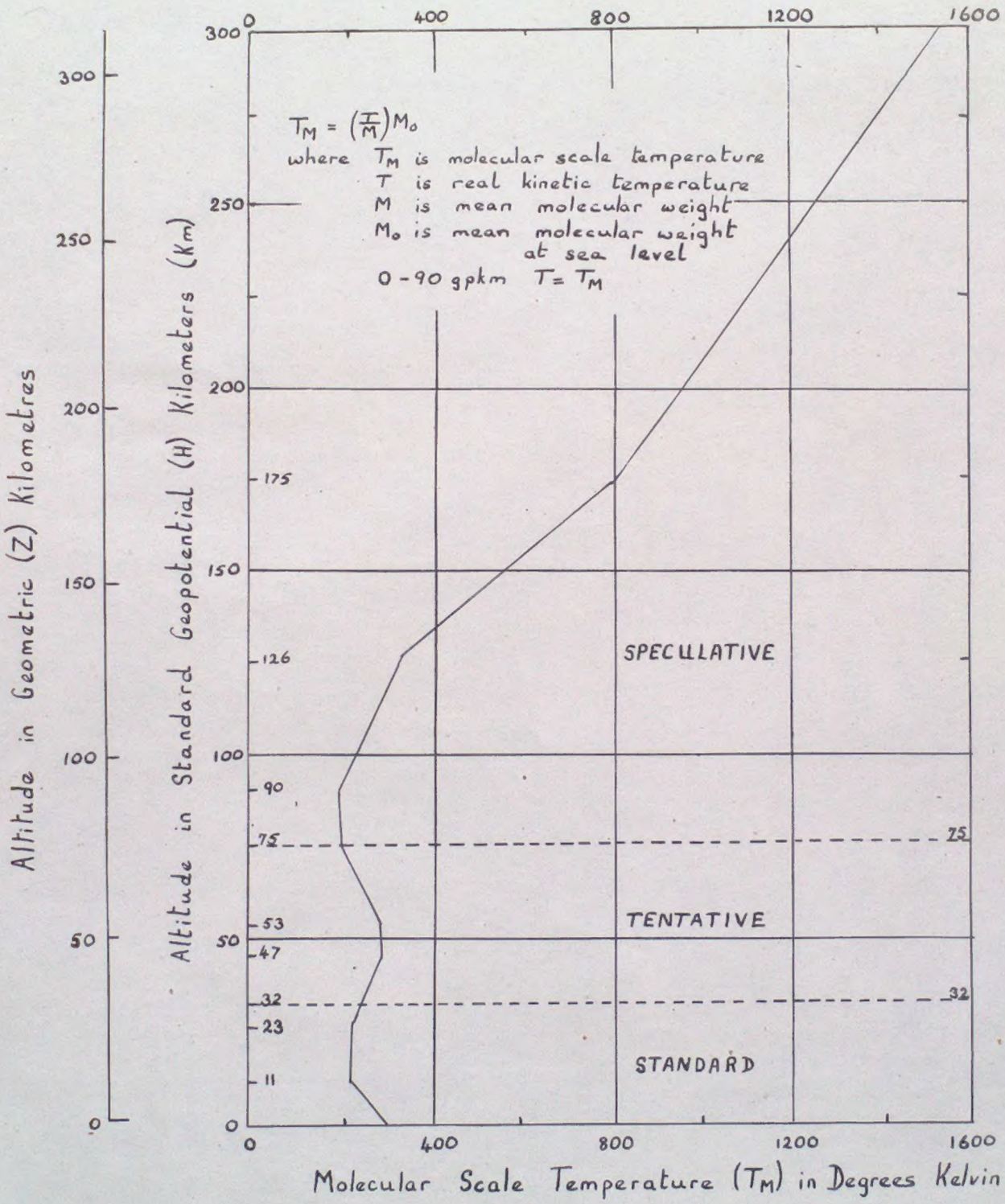


FIGURE 1. MOLECULAR SCALE TEMPERATURE VS GEOPOTENTIAL ALTITUDE.